

UNCLASSIFIED

Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author)

Naval Personnel Research and Development
Laboratory, Washington Navy Yard
Washington, D. C. 20390

2a. REPORT SECURITY CLASSIFICATION

UNCLASSIFIED

2b. GROUP

N/A

3. REPORT TITLE

A REVIEW AND ASSESSMENT OF THE SHIP II SIMULATION MODEL

4. DESCRIPTIVE NOTES (Type of report and, inclusive dates) Final General Summary and Technical Evaluation Report - July 1971-June 1972

5. AUTHOR(S) (First name, middle initial, last name)

Melvin A. Schwartz

6. REPORT DATE

15 July 1972

7a. TOTAL NO. OF PAGES

50

7b. NO. OF REFS

32

8a. CONTRACT OR GRANT NO.

9a. ORIGINATOR'S REPORT NUMBER(S)

b. PROJECT NO. TDP P43.07X B2.33W

WTR 73-4

c.

9b. OTHER REPORT NUMBER(S) (Any other numbers that may be assigned this report)

d.

10. DISTRIBUTION STATEMENT

Approved for public release; distribution unlimited

11. SUPPLEMENTARY NOTES

N/A

12. SPONSORING MILITARY ACTIVITY

Bureau of Naval Personnel
Washington, D. C. 20370

13. ABSTRACT

It was the purpose of this study to review all prior research application of SHIP II, a large scale computer simulation model of a total ship which can be used in manpower studies, and then, to evaluate the technical adequacy and financial feasibility of using the model.

The approach to the study include review of research documentation, evaluation of each previous study, and synthesis of result. It was concluded that the SHIP II model has adequately met criteria of face validity, reliability, and others and is a useful tool for manpower research.

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DD FORM 1473

NOV 68

(PAGE 1)

0101-607-6811

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KEY WORDS

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HOLE

Computer Simulation
Manpower Models
Simulation Modeling

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WTR 73-4

AD

JULY 1972

A REVIEW AND ASSESSMENT OF
THE SHIP II SIMULATION MODEL

Work Unit No.
TDP P43.07X.B2.33W

Melvin A. Schwartz

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NAVAL PERSONNEL RESEARCH AND DEVELOPMENT LABORATORY
WASHINGTON, D. C. 20390

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FOREWORD

This investigation was conducted in support of Advanced Development Objective, ADO 43.07X; Manpower Management Effectiveness which summarized the need for simulation models of ships, aircraft, and shore activities to permit consideration of trade-offs between manpower and other significant parameters in an operational environment.

The cooperation and timely response of the Research Computation Center, Naval Research Laboratory, is acknowledged with appreciation.

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Problem

There is a growing need for a model which can be used to answer questions immediately after it is developed but before it has been tested. The SHIP II development and evaluation effort differs from most modeling efforts in two respects. First, SHIP II was developed as a general manpower research vehicle. Many variables and relationships can be investigated through its application. With data changes, the model can be made to represent a variety of ship classes. Because the model was developed as a general research tool, the demand for its immediate application (outside of the context of model research and development) was not present. Second, the capability under development at the NAVPERSRANDLAB encompasses the range of techniques research, model development, and application of models to manpower research. The development and application of an appropriate model evaluation technology which considers criteria and specific techniques for comparing models is viewed as an integral part of the capability.

Objectives

It was the purpose of this study to test the SHIP II research applications of SHIP II and to determine their validity in order to assess the technical, economic, and financial feasibility of using the model.

Background

Operational constraints frequently require a model to be used to answer questions immediately after it is developed but before it has been tested. The SHIP II development and evaluation effort differs from most modeling efforts in two respects. First, SHIP II was developed as a general manpower research vehicle. Many variables and relationships can be investigated through its application. With data changes, the model can be made to represent a variety of ship classes. Because the model was developed as a general research tool, the demand for its immediate application (outside of the context of model research and development) was not present. Second, the capability under development at the NAVPERSRANDLAB encompasses the range of techniques research, model development, and application of models to manpower research. The development and application of an appropriate model evaluation technology which considers criteria and specific techniques for comparing models is viewed as an integral part of the capability.

Because of these differences it has been possible to plan for and conduct evaluations prior to, or at least simultaneously with its application on specific systems.

Findings

The results of the study indicated that the STP model can be used effectively in studies:

1. Alternative methods of force reduction
2. Effects of ship tempo of operation on workload
3. Effects of equipment reliability on maintenance skill utilization and spare availability
4. Effects of altering skill level on capability to accomplish ship's work and maintenance
5. Workload balancing problems

Model deficiencies currently include a lack of serious treatment of human performance variables, failure to simulate in port activities, a need for highly specialized personnel for model applications and a restriction on the type of computer on which the model may be used.

Conclusions

1. It was generally concluded that the STP model does not adequately meet criteria of face validity, reliability, practicability, relevance and sensitivity for those variables thereby treated. Dependent variables were examined in all categories of workload, equipment availability and capability of the crew to meet task requirements. Independent variables were limited to tempo

There are two basic methods for applying the SHIP II model to manpower problems.

a. The construction of alternative input data sets and statistical comparison of outputs.

b. The iterative approach which starts with successive input following a careful study of previous obtained output. Both methods are useful in treating manpower problems, the latter being most useful for preliminary planning purposes. (p. 41)

Recommendation:

1. It is recommended that future test and evaluations of SHIP II should be guided by specific needs for applications on the part of potential research consumers. (p. 43)

2. It is recommended that subsequent tests of output distribution characteristics be conducted. (p. 43)

3. The iterative method of application should be further explored with a variety of manpower problems. (p. 44)

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I. INTRODUCTION

A. Problem

Since the inception of the Total Ship Simulation Model Project, the SHIP II model has undergone several major revisions, the requirements for which were made evident through attempts to apply the model to the solution of a variety of manpower and personnel research problems. The result is, broadly speaking, a third generation, large scale, Monte Carlo, computer simulation model of a destroyer class ship.

There is a growing need in the Navy for the development and use of manpower planning and research tools such as the SHIP II model, but there is a concomitant increasing concern with the technical adequacy and cost of developing and using such tools.

The problem addressed in this report has been accurately stated in a previous evaluation of the SHIP II model:

"In the field of simulation technology it is more common than not to find that research applications of computer simulation models, and the decisions based on such applications, preceded objective evaluations of the models involved. Further, many models used for prediction and design evaluation are never subjected to objective comparisons with alternative methods. The reasons for this situation are:

- Lack of an adequate model evaluation technology

In the past, social sciences, particularly psychology, have relied heavily on statistical methods and concepts originally developed in the biological sciences. Social scientists have modified and expanded the techniques and have built a formidable "armamentarium" for research. Existing techniques are being applied to the analysis of outputs of simulation models, presumably so that planners can have confidence in their decisions. The questions of model validity, reliability, and utility are rarely addressed because existing techniques are unwieldy for this purpose.

Central to this problem of the lack of a workable evaluation technology is the fact that theoreticians have failed to translate general model characteristics which should be "considered" during evaluation into specific operational criteria. An objective evaluation must provide for the measurement of the characteristics under consideration. One obstacle to progress has been the theoreticians' reluctance to scale and propound units of measurements where human judgement is concerned. The research consumer, on the other hand, is intimately familiar with the judgemental aspects but does not have the technical knowledge, incentive or the time to set forth the considerations in the required fashion.

• Operational constraints

Typically, once the modeling concepts have been developed to provide planners with the categories of information they need, the model and data development efforts are completed at a point in time in the planning process when vital decisions must be made. A quick "answer" must be generated. Hence, model runs are made, output data analyses are conducted and there is not enough time to answer the question, "How good was the model that produced the results?" This is particularly true when models are developed to answer specific questions concerning specific systems rather than to handle a broad class of problems.

Another constraint on model evaluation is cost. Given that available funds are limited, managers are more prone to devote funds to efforts which result in a visible product -- answers to operational questions, than to allocate resources to a less obvious product -- assurance that the answer is accurate and that the technique is reliable.

It cannot be in the best interest of the naval research and development community to use untested simulation models in the planning process, regardless of the underlying reasons, simply because bad decisions could be the result. A bad decision is one that leads to:

1. excessive system cost or research cost,
2. excessive development time, or
3. poor system performance."

(Ref. 8, pp. 1-2)

B. Purpose

It is the purpose of this report to review all prior research applications of the SHIP II model and to synthesize past findings in order to assess the model from the standpoint of technical adequacy and cost.

C. Background

In June 1967, following the successful application of a simulation model, COSIMO, to personnel research problems, the Bureau of Naval Personnel (Pers-A33) initiated exploratory development research (EDR)* concerned with the development of a Total Ship Simulation Model (TSSM). The purpose of the research was to test the feasibility of developing a simulation model of an entire ship so that personnel research could be performed at the total system level.

The EDR was completed in June 1968 and was reviewed by the advisory group.** The results of the review, despite a variety of cautions concerning cost, scope and validity, were generally favorable and plans were made to continue the research into the advanced development phase (Ref.19). These plans provided for model improvement, data refinement and the training of Navy personnel in the use of the TSSM (Ref. 25).

In November 1968, a Ship Simulation Research Modeling Unit was formed at the Personnel Research Laboratory (PRL). The unit, composed of two analysts, began to analyze and evaluate the prototype TSSM (Refs. 19-23) as part of

* The Bureau of Naval Personnel (Pers-A33) contracted with Serendipity, Inc. to have the TSSM developed. At the same time, an advisory group, composed of representatives of various Navy organizations was formed to provide guidance to the effort.

** Additionally, Serendipity, Inc. conducted a seminar for potential model users in June 1968.

the larger advanced development effort.* The purpose of this effort was to qualify (train) three Navy analysts in all aspects of simulation and to refine the TSSM and its data base.** The Naval Research Laboratory (NRL) provided computer time and services (Control Data Corporation 3800 computer).

In January 1969, the Naval Personnel Research and Development Laboratory (NAVPERSRANDLAB), formerly PRL, Ship Simulation Research Modeling Unit relocated to the contractor's facility and began to play an extremely complex and difficult role. They were responsible for the analysis and evaluation of the TSSM and were, at the same time, students of the contractor in simulation modeling. The technical effort was realigned in January 1969 and team training was primarily focused on data refinement problems. Relatively little attention was devoted to TSSM characteristics and experimental uses of the model.

By April 1969, following refinement of the data base the first analytic study*** (Ref. 26) was performed. Immediately following the application, the model was reprogrammed and the second generation model (SHIP II) emerged. SHIP II has been modified and improved many times since.

In May 1969, a set of functional and organizational concepts for the conduct of simulation research at the NAVPERSRANDLAB was formulated. The original technical scope of modeling research at NAVPERSRANDLAB was expanded. The increased scope was due partially to the desire for a center of capability in simulation technology on the part of the Bureau of Naval Personnel. Objectives of the program were expanded. The emphasis, however, remained upon the SHIP II model, and toward the end of 1969, when SHIP II had been improved, it was recognized that the basic SHIP II modeling concepts and techniques could be used to perform studies of a variety of ship types and that the model could be used for early manpower research during system planning and design.

* Advanced Development Objective, ADO 43-07X.

** The TSSM was a general destroyer model, the data base was from a DDG-2 class ship.

*** A comparison of model output statistics to requirements set forth in the Ship Manning Document (SMD) for the DDG-2 class ship.

However, a more thorough understanding of the statistical characteristics of model output was required before regular application to manpower research problems could begin. Subsequently, a number of studies using SHIP II have been performed.

The basic purpose of all of these studies has been the exploration of model sensitivity, validity and utility. Each of the studies will be discussed in a subsequent section of this report.

As mentioned previously, operational constraints frequently require that a model be used to answer questions almost immediately after it is completed, but before it has been tested. The SHIP II development and evaluation effort differs from most modeling efforts in two respects. First, SHIP II was developed as a general manpower research vehicle. Many variables and relationships can be investigated through its application. With data changes, the model can be made to represent a variety of ship classes. Because the model was developed as a general research tool, the demand for its immediate application (outside of the context of model research and development) was not present. Second, the capability under development at the NAVPERSRANDIAB encompasses the areas of techniques research, model development, and applications of models to manpower research. The development and application of an appropriate model evaluation technology which considers criteria and specific techniques for comparing models is viewed as an integral part of the capability.

Because of these differences it has been possible to plan for and conduct model evaluations prior to, or at least simultaneously with, its application on specific systems.

II. APPROACH

A. Methodology

Modeling technologists and the consumers of manpower modeling research place different emphasis on the criteria used in evaluating a simulation model.

Research consumers, including system acquisition managers, personnel planners and system designers, are greatly concerned with the relatively narrow operational problems which the use of a model can help solve. Because of this, practical criteria, such as cost, the meaning of results for their purposes, and timeliness of output, receive the most attention. Modeling specialists, on the other hand concern themselves more with the technical design characteristics of models, e.g., programming logic, output reliability, etc. Naturally both the modeling expert and the research consumer must consider validity and problem relevance.

The essentials of a sound technical evaluation of a simulation model are:

- criteria, defined in operational terms and which permit measurement and quantification.
- a procedure for combining the results of applications of each criterion or a scheme for interpreting evaluation results.
- sufficiently detailed information describing the model, its objectives and uses.

B. Procedures

These technical requirements were satisfied in the current evaluation, viz.

- Criteria were established for each application study using the model. They included:
 - a. Validity
 - b. Reliability
 - c. Practicality

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These criteria are defined in more detail for each of the applications discussed in this report (Ref. 6).

- The systematic description of research conducted using SHIP II, combined with the later evaluative discussion comprise the scheme for presenting and interpreting results.

- A systematic description of the model objectives and technical characteristics was available. (The overall SHIP II research, development, and test effort is shown in Figure 1 (Ref. 9 and 10)).

C. Data Collection

The basic approach to the current assessment included the following steps:

- Review of all SHIP II documentation
- Analysis and description of prior research and development
 - Summary evaluation of each study
 - Synthesis of results
 - Documentation

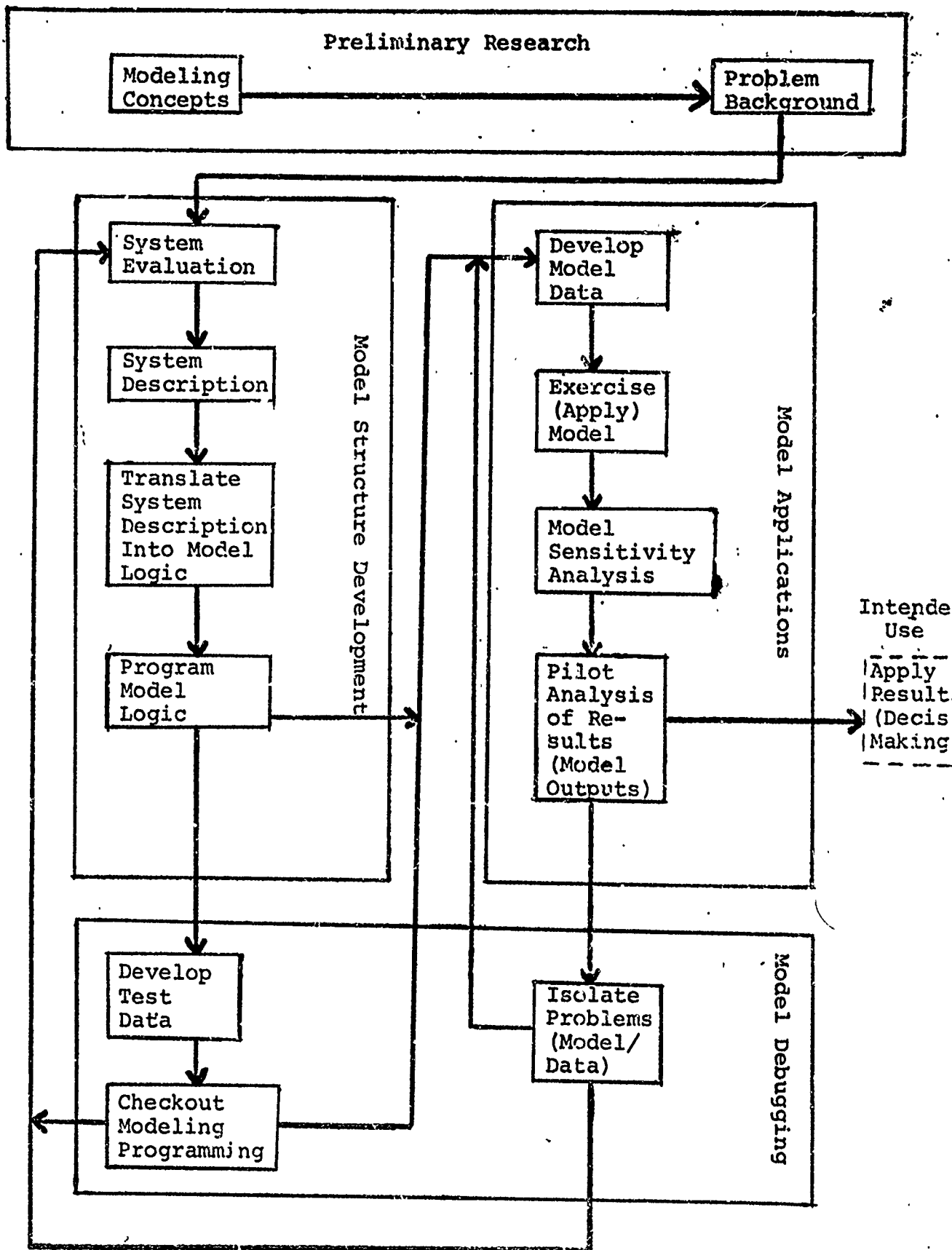


Fig. 1. -- SHIP II Research Development and Test Approach

III. RESULTS

A. Summary Description of the SHIP II

A comprehensive description of SHIP II is provided in references 9 and 10 and is too voluminous to be incorporated directly into this report. However, a sufficient summary description to base an evaluation upon is presented in this section.

The SHIP II model was developed to demonstrate the feasibility of using computer simulation models for a broad spectrum of personnel research studies including the investigation of alternative manning concepts, maintenance and work policies, training concepts, and equipment design characteristics. SHIP II was designed to reflect realistically the many dynamic and complex interrelationships among shipboard equipment, personnel and operational and maintenance task requirements for planned and existing ships in the fleet.

The model was originally developed using a guided missile destroyer, a DDG-2 class ship, as the referent system, but the basic model concepts, logic and techniques are in fact independent of the referent system. SHIP II can be applied to studies on a variety of ship types which are functionally similar to the DDG-2.

Technical Characteristics of the Ship Simulation Model

SHIP II is an event-oriented, digital model which uses the Monte Carlo method for producing random samples of events from empirically derived frequency distributions. At the beginning of each simulation run a list of events is generated and placed in a transaction table along with the time of event occurrence. Before each event is initiated a subroutine searches the transaction table to determine the particular event which is to occur and advances the clock to the time associated with that event.

Events include the assignment of personnel to watches, maintenance and work, equipment failures, training exercises and classes, and other activities and occurrences aboard ship. The model is driven by a scenario which lists initiation times and durations for basic operational requirements such as training exercise, changes in readiness conditions and evolutions.

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The programs are written in FORTRAN IV and currently operate on a Control Data Corporation 3800 computer at the Naval Research Laboratory. Because of the size of the model and the requirement to store huge quantities of data (over 150,000 unique array positions are required to store the data used by the programs) a data compression technique known as bit-packing was employed in the program. Additionally, overlays and segments are employed to accommodate the programs. The model contains one hundred and twenty-eight subroutines. Many of the subroutines perform the basic functional simulation of such events as watch assignment and training exercises, others perform utility functions such as bit-packing, input and output, while still others perform executive functions which control the initiation of program subroutines.

SHIP II is modular; individual subroutines can be easily removed and modified without extensive reprogramming of the rest of the model.

One interesting feature of the model is the inclusion of factors called parametric variation ratios, which can be used to uniformly alter values of selected data categories. For example, if the value of one of these factors is set to 1.0 no change will occur, if set to 0.8 a 20 percent reduction in the specified variable will occur and if set to 1.2 a 20 percent increase will result. The frequency distributions employed in the production of random events such as equipment failures and certain tasks can be changed easily.

In SHIP II the input variables which can be altered by application of parametric variation ratios are:

- Training Session Duration
- Hours/Week/Man
- Failure Detection Times Under Cond. I
- Failure Detection Times Under Cond. III
- Failure Detection Times Under Cond. IV
- Failure Detection Times Under Cond. V
- Failure Detection Probability During PM
- Operation % at Cond. I
- Operation % at Cond. III
- Operation % at Cond. IV
- Operation % at Cond. V
- Mean Time Between Failure

Probability of Degradation
 Deferrals for Assistant: Prob.
 Deferrals for Assistant: Mean
 Deferrals for Assistant: Stan. Dev.
 Deferrals for Parts: Prob.
 Deferrals for Parts: Mean
 Deferrals for Parts: Stan. Dev.
 Time in Function: Mean
 Time in Function: Stan. Dev.
 Error Probability: P1
 Error Probability: P2
 Error Probability: P3
 Error Probability: PT
 Delay Times (DT)
 Time in Function: Mean
 Time in Function: Stan. Dev.
 Error Probability: PD
 Error Probability: P2
 Probability - PTR/PTR
 Time in Function: Mean
 Time in Function: Stan. Dev.
 Manhours/Day
 % Carryover for Ships Work

The model uses the exponential distribution for determining equipment failure times and the log normal distribution for producing corrective maintenance times.

The model output statistics are currently compiled on a weekly basis, that is, each week serves as a data point for all output variables. However, it is a simple matter to alter the interval of time over which data are compiled.

For any given simulation application the model can currently handle about 350 men and about 500 pieces of equipment. It is possible to accommodate larger manning and equipment sets by reallocation of core memory and reducing the numbers of other variables treated.

The SHIP II program and its modifications are stored on IBM cards and tapes and input data are also on cards and tapes. Model outputs can take the form of tape, card, or hard copy. The particular nature of the application dictates what medium is used for input or output. Running time for the model is about 40 minutes per simulated week for an entire ship of 300 men, 500 equipment

items, and about 20 mission types. This is reduced to about 3 minutes of computer time per week of simulation when simulating a single division of about 20 men, 100 pieces of equipment and the same number of mission types.

Development of the Model

The steps in the development of SHIP II are presented in Figure 2. The specific design of SHIP was based on considerations in four major areas:

- factors of interest to Navy planners,
- measures of system performance,
- availability of sufficient data, and
- current state-of-the-art in simulation programming.

Determining the factors of interest to Navy systems analysts involved an examination of the questions personnel planners would submit for solution via simulation.

Measures of system performance were chosen that would be useful in examining alternative concepts of system design and planning. The primary measures selected were statistics reflecting manpower utilization and equipment availability.

Data limitations and the state-of-the-art in simulation programming placed dual constraints on the model design. Data problems included:

- data unavailability,
- unreliability of data that were available, and
- the cost of data acquisition and preprocessing for input.

State-of-the-art problems included programming limitations and computer memory and processing time constraints. Because of the size and complexity of the program, simulation languages such as SIMSCRIPT were deemed inadvisable. For this reason the program was written in FORTRAN IV.

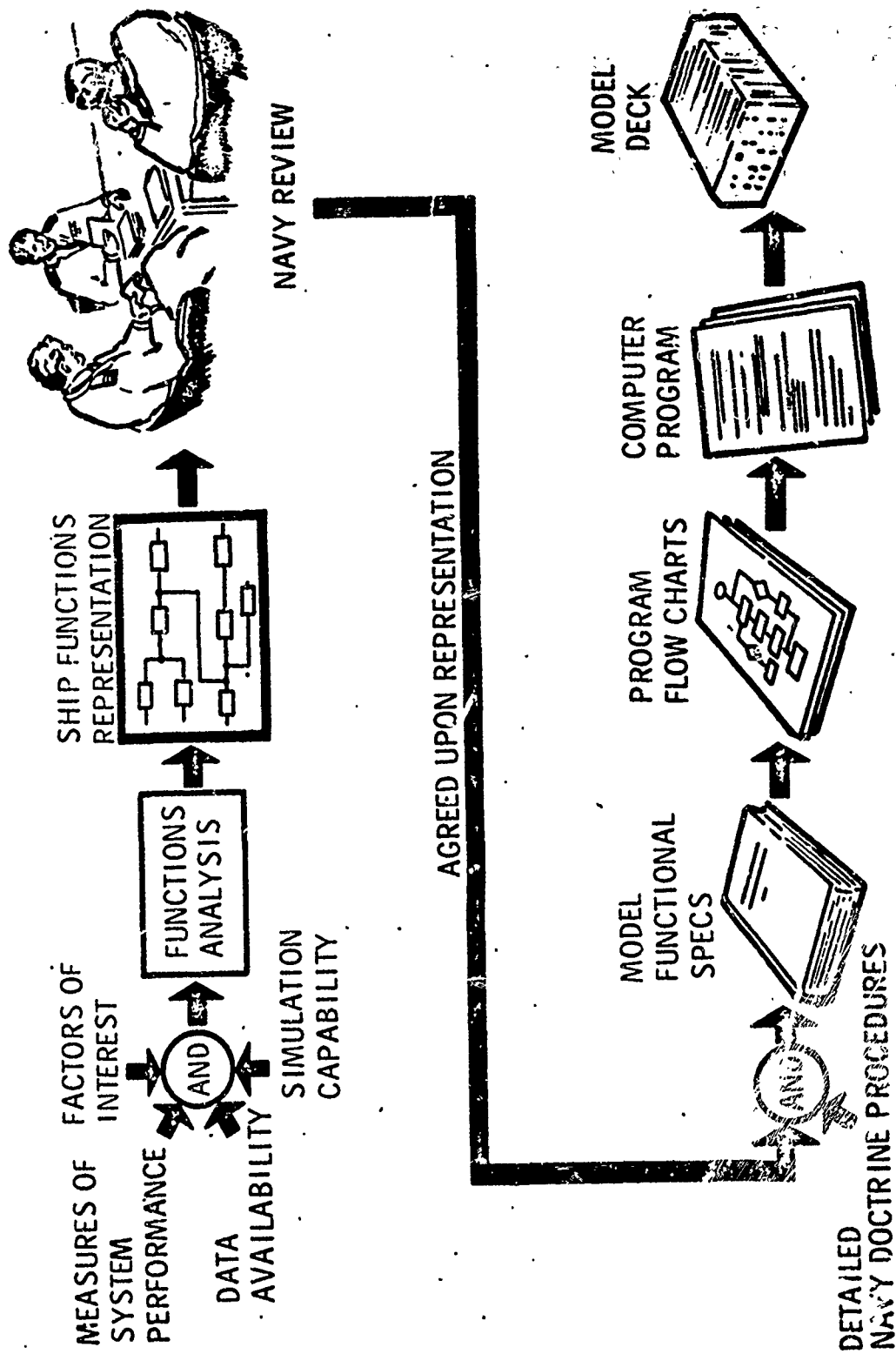


Figure 2. Steps in development of SHIP II model.

After the general model design characteristics were determined, the development effort centered on modeling specific ship functions.

The first problem addressed was the selection of functions. Since the program was to simulate an entire ship for manpower research, it was decided that every shipboard function involving human performance was to be treated. These functions included the performance of watch, evolutions, exercises, division training, and the various classes of maintenance and ship's work.

The general procedure followed in modeling ship functions was to develop a logic flow chart of the processes and activities taking place on the ship, then convert that into a computer program flow chart, then on to programming, keypunching and finally debugging. The problems of model validity and verisimilitude were always an important consideration. Since some of the intended model uses preclude empirical validation of results, particular attention had to be devoted to ensuring the correspondence of program logic to real-world processes. Operational fleet personnel were consulted extensively during functional design. There were two factors during this process which seemed at cross-purposes; compromises had to be made between the desire for face validity of the model and the programming limitations. In cases where artifacts were introduced to simplify programming, they had to be constructed so as not to introduce variation not found in the real-world. Real-world processes not considered relevant to the model outputs were excluded.

Output Data

The selection of outputs for the model program was dependent on two major considerations. The first was the potential research areas for which the model would be used. The output variables had to be selected carefully so that they would be relevant to the study of manning concepts, work policies and other types of personnel research. Second, an important concern was the susceptibility of the model output data to analysis. Program output reports which merely recounted the events that had taken place during the simulation would not necessarily be useful in the solution of the problems toward which certain model runs would be directed. The model output reports had to be organized in such a way that relevant

statistics could be accumulated and analyzed. It was decided that output data would be accumulated in four major categories:

- manpower data,
- equipment information,
- task data,
- ships readiness.

The manpower data comprise the hours spent on the various tasks, organized by individual man, ship organization, and by skill category. Equipment data include operating times, failure data, and repair information, such as repair time required, and repair errors made. Task data include tasks performed, time spent on various tasks and tasks remaining undone. Readiness data include total ship readiness and the contribution of each mission oriented equipment subsystem toward ship's readiness.

Input Data

The four major input data categories for the model are manning, equipment, tasks and ships readiness. Manning data comprise skills, that is, skill types and skill levels; and organization -- the shipboard organization of men into departments and divisions. Equipment data include the organization of equipments into subsystems according to their mission functions, reliability data, and maintainability information, including mean-time-to-repair (with variance), the requirements for special troubleshooting actions, and the frequency of maintenance deferrals for assistance or spare parts. Task data include requirements for watch-standing, ship exercises, evolutions, division training, corrective maintenance, planned maintenance, and ships work. Ships readiness data include readiness rating tables for the entire ship, and for each equipment subsystem required for mission performance.

The level of detail of input data for the SHIP II model is not the same as many simulation models treating detailed aspects of system performance. For example, using simulation to study performance in a combat information center, one model was developed which treats the location of equipments within the CIC and the performance times for each molecular

task as discerning a dot on the radar scope, reporting the location of the dot, and responding to that information by transmitting a weapons control command. SHIP II models all major shipboard functions in a more general way. For instance, in the area of corrective maintenance, rather than representing the performance of each individual maintenance task to the part level, SHIP II treats the maintenance tasks as single events with average performance times and standard deviations. At this level of detail one can study the interactions of all of the various tasks taking place aboard the ship and the interactions of the priority system that orders the performance of these different tasks.

Data Sources

As illustrated in Figure 3, the input data set can be produced by one of two methods, the choice of which depends on the problem to which the model is being addressed. First, for the investigation of a ship or shipboard system currently in operation, data can be acquired and analyzed from a number of Navy data sources: The Maintenance Material Management System (known as 3-M) provides maintenance data on the corrective maintenance of shipboard equipments; there is a Casualty Reporting System (CASREPT) which also provides data on shipboard equipment reliability, especially insofar as they pertain to the readiness of the ship; the Ship Manning Document provides information about shipboard manpower organization and about ships work tasks, that is facilities maintenance and administrative tasks which are performed on a day-to-day basis; the planned maintenance system, specifically the maintenance index pages (or MIPS) provide data for the planned maintenance requirements for each equipment onboard the ship; and finally the deck-logs of ships in the fleet provide information about the ships operation, i.e., training exercises, evolutions and special details, which are used to generate a scenario of operation.

Second, if the ship being investigated is not yet in the fleet, if it is a proposed ship or a ship in an intermediate design stage, the data from the above sources may not be available. Data for a new ship can be generated either from similar data from other ships or from data from the contractor or the project office. These latter data may be approximations or estimates.

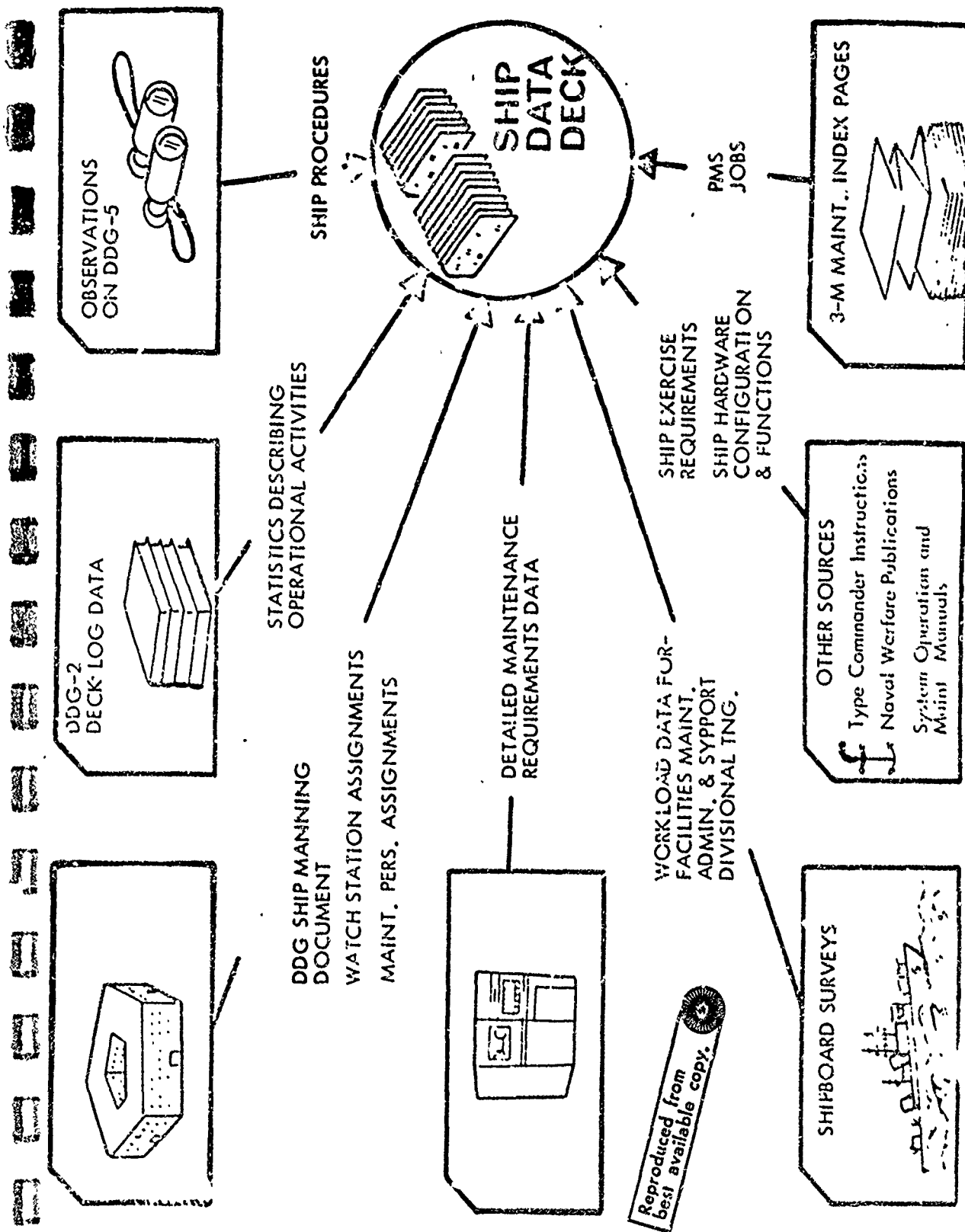


Figure 3. Sources of input data for SHIP II model.

B. Technical Summaries of Previous Applications

Each of the studies conducted using the SHIP II model will be described in this section according to the following format:

1. Background
2. Objective
3. Scope
4. Method
5. Results
6. Evaluative Comment

I. Comparison of the Total Ship Simulation Model Output to Ship Manning Document (SMD) Requirements (See Ref 26)

1. Background

After the TSSM had been completed and the DDG-2 data base revised, the need for model logic changes was identified and the development effort was continued.

There was a requirement to test model validity and economic feasibility and the development and test schedules could not be satisfied by the contractor. Consequently, the tests that were conducted did not involve the model and data that comprise the latest version of the model, but the contractor felt the basic structure and concepts were similar enough to use the older version of the TSSM to meet the testing requirement.

2. Objective

This comparison study was intended to demonstrate the analytic and economic feasibility of utilizing the TSSM (actually TSSM concepts) for manpower planning research. Of specific interest was the "validity" of workload and readiness statistics (validity here being defined as the degree to which the model outputs conformed to a set of SMD requirements).

3. Scope

The TSSM/SMD comparison was based on DDG-2 data:

- All enlisted men (319) from SMD
- Planned Maintenance (PM) task list prepared from MIP's (800 jobs)
- Equipment list and Corrective Maintenance (CM) data prepared from Maintenance Data Collection System (MDCS) data (400 equip. items)
- Ship's work jobs (127 tasks) from SMD
- Exercises (34 types) from type commander instructions

4. Method

a. General Approach

The approach was to perform a simulation of a typical period of operations of the DDG-2 class ship, and to compare the outputs of the simulation to the data in the SMD. The implicit assumption was that the SMD data would reflect the real world. The basis for comparison was the set of work statistics: manpower workload, tasks completed, tasks undone. Equipment statistics were produced in the runs, but did not contribute to the comparison because there are no equipment data in the SMD.

There were two sets of comparisons: simulation vs SMD and run vs run. The simulation vs SMD served the primary purpose of the study; the run vs run comparisons were made to investigate the statistical characteristics of the model. Comparisons were based on mean values and graphs of time series.

b. Study Steps

- Data collection and preparation - data were collected from 5 main sources: SMD, maintenance index pages, MDCS, type commander instructions, deck logs. Data were entered on prepared data forms and key punched.

- Data set was "debugged" - rid of errors of format and consistency.
- Simulation was run (3 runs) for debugging purposes.
- Errors discovered in initial runs were corrected.
- Simulation was re-run (2 runs) for data.
- Data were prepared and comparisons (simulation vs SMD and run vs run) were made.

5. Results

a. The data collection effort was extensive. Data were in a variety of forms that had to be processed, combined, collated, and distilled for input into the model.

b. The preliminary runs disclosed some major flaws in the model/data:

- Some PM jobs with long times were in a perpetual queue.
- PM data did not account for multiple copies of equipments.
- Some large CM times selected from the log-normal distribution caused perpetual queues for CM.

These discrepancies were alleviated by subsequent data and program changes.

c. The final runs produced data that were compared to the SMD data and to each other. The SMD comparison showed agreement for watchstander workload, less agreement for non-watchstander workload. The non-watchstander discrepancy was primarily in the areas of ship's work accomplished (not all was done) and maintenance demands (based on MDCS rather than PM/CM ratio).

6. Evaluative Comment

a. The run-to-run comparisons demonstrated the consistency of the basic model and showed the types of data that the model produced that could be useful for investigating manning problems. They were primarily qualitative - although the numbers were tabulated and graphed, no statistical analyses were performed on the values.

b. The data refinement effort was extremely time consuming.

c. The version of the model used had sufficient deficiencies to warrant reprogramming. Because of the extensive nature of the changes, the analytic conclusions derived from this study are not believed to pertain to any direct evaluation of the current version of the model (SHIP II).

II. DDG-2 Reduced Manning Study (See Ref. 8, Appendix B)

1. Background

Working with the Chief of Naval Operations (OP-100) and NAVPERSRANDLAB the contractor was required to demonstrate model utility. The study addressed the question, "What are the effects on workload distribution, readiness, etc., of reducing the manning level on the ship?".

2. Objective

Purpose was to compare two manning levels of DDG-2 to demonstrate how the model could be used in manpower research.

3. Scope

This study was based on the full set of DDG-2 manning data and scenarios provided by OP-100.

4. Method

a. Configure model with standard manning set.

- b. Run a typical scenario, collect data.
- c. Reconfigure data base to reflect reduced manning.
- d. Run with same scenario, collect data.
- e. Compare results, determine effects of reduced manning.

5. Results

When manning was reduced, individual manhours increased, ships work undone increased, amount of Division training decreased and maintenance jobs undone increased. Queues were more numerous.

6. Evaluative Comment

- a. The study demonstrated potentially useful types of applications.
- b. The a priori hypotheses concerning effects were in general confirmed following a statistical analysis of results.

III. DDG-2 Sensitivity Analysis (See Ref. 8)

1. Background

There was a need to determine if selected output variables of the model responded to changes in independent variables associated with equipment maintenance and ships work. This study was one of the first attempts to do sensitivity testing of the model.

2. Objective

It was the purpose of this study to compare responses of 15 output variables (including planned and corrective maintenance, manhours, queues and length of time in queues, readiness, cancelled work, etc.) resulting from changes in equipment reliability input (mean time between failures) and task times (Time-in-Function (TIF)).

3. Scope

The study was based on the full set of DDG-2 data used in previous applications.

4. Method

a. Configure model with standard data set; run standard scenario collect data.

b. Make input changes to MTBF and conduct runs using same scenario for each level of MTBF (MTBF X 1.2, MTBF X 1.4 and MTBF X 1.6), collect data.

c. Make input changes to TIF and repeat b. for TIF X .625, TIF X .714 and TIF X .833, collect data.

d. Analyze results using Studentized Range Test methods.

e. Determine effects on each of the 15 output measures of altering MTBF and TIF.

5. Results

The overall impact of varying both the TBF and the TIF parameters is minor in light of the changes induced in the 15 model output categories studied. Variability of tempo of operation appears to exceed the influence of changes in TBF and TIF. The result of varying TIF is possibly more evident when presented graphically, but none of the differences between BL, TBF and TIF conditions were statistically significant at the 0.1 level when tested with a form of studentized range test. The lack of practical and/or statistical differences in this analysis could result from a model which is insensitive, a poor choice of parameters to vary, or a choice of unsuitable output data categories to study.

The amount of corrective maintenance work done during a model run is independent of the other ship work done, primarily preventive maintenance. The CM workload tends to have a large impact on the workloads/work patterns of certain critical ratings (e.g., ETs), since fluctuations in equipment failures, sometimes only one piece of equipment, can cause exaggerated fluctuations in weekly workload output statistics.

The system readiness measures in terms of percent C-1 may be a poor measure, in general, due to the rigidity of the readiness scoring method. In terms of ship operation, the incidence of deferrals seems to overly influence the % C-1 statistics and one equipment failure may degrade a whole subsystem, even if there is some form of back-up equipment that would be brought into service under actual fleet operating conditions.

6. Evaluative Comments

a. This study pointed out the "masking effects" of logistics problems. That is, due to large equipment downtimes because of deferrals for parts, readiness degraded to the point where the scheduled scenario events could not take place. In terms of operational requirements the effect seemed realistic but did not allow a thorough examination of the exclusive effect of manipulating the independent variables. Subsequent analysis limited the range of possible deferral times.

b. The finding that model outputs were more sensitive to changes in tempo of operation than to MTBF or TIF changes agrees with expectations and increases confidence that the model behaves realistically.

IV. SHIP II Sensitivity Analysis (See Ref. 14)

1. Background

All previous applications of the model had been at the total ship level and analyses had dealt with a small range of variation in independent variables.

The need for more quantitative sophisticated evaluation of response characteristics of SHIP II was recognized along with the requirement to demonstrate utility to potential users of model outputs.

This dual purpose study was designed to satisfy those needs simultaneously.

2. Objectives

a. To test the applicability of SHIP II to a smaller data set with greater detail.

b. To investigate the sensitivity of a number of output measures to the input variable - scenario load.

c. To aid PMS 389 in evaluating a specific proposed manning plan.

3. Scope

The study concerned the ASW division of the DD-963. The data set included:

- 20 men in 4 rating groups
- 17 watch stations
- 11 subsystems, including 100 equipments
- 113 PM tasks
- 11 Ship's work jobs
- 5 types of training exercises

4. Method

a. Determine scale and levels for the independent variable - scenario load.

b. Select dependent variables

c. Collect input data

d. Pilot run and analysis

e. Study runs

f. Output data collection/collation

g. Statistical tests and analysis

h. Interpretation of results

5. Results

a. Mean values for each output variable in each run were tabulated. Variables were:

- Watch hours, individual and total
- Divisional training hours
- Evolution hours
- PM hours
- CM hours
- Ship's work hours
- Total hours
- CM hours, Rating/Rate and NEC
- PM hours, Rating/Rate and NEC
- Queues for Rating/Rate and NEC
- Interrupts due to unavailable Rating/Rate and NEC
- Readiness ratings
- PM jobs scheduled
- Ship's work undone
- Division training sessions

b. Mean values of dependent variables from different scenarios were compared for statistically significant differences, using the randomization test for two independent samples.

c. Linear relationships between dependent variables and scenario load were investigated by calculating regression lines and correlation coefficients.

d. In a special (unscheduled) study, the effects on performance of a reduction in maintenance skill was investigated. The number of men for the two treatment conditions remained the same but the subject NEC was reduced. The output variables, watchstanders workload, non-watchstander workload, total workload, PM jobs cancelled, and ship's work undone were studied. It was found that a reduction in number of NEC's was feasible.

6. Evaluative Comments

a. The study demonstrated that a number of dependent variables responded well (i.e., were sensitive) to manipulation of the independent variable "scenario load" or tempo of operations.

b. The conduct of this study aided NAVPERSRANDLAB in the refinement of application procedures and had the effect of sharpening insights for future application.

c. It demonstrated that the model could be used to handle sub-optimization (less than total ship) problems.

d. An actual consumer found results useful in manpower planning (for the DD-963 class).

V. DD-963 Baseline Runs (See Ref. 17)

1. Background

The immediate basic technical requirement of PMS 389 had been satisfied through previous applications of SHIP II. PMS 389 wished to be in a technical position to answer later questions concerning the entire ship through use of the model. (The previous applications concerned only the ASW division.)

2. Objective

The DD-963 baseline simulation study was performed to provide a base of output data, for a wartime operating environment, which could be used for comparison in performing future analyses.

3. Scope

The data set for the DD-963 was used. It included:

- 232 men, in 12 divisions
- 214 watch stations

- 36 subsystems, including 373 equipments
- 283 PM tasks
- 138 Ship's work tasks
- 34 training exercises

4. Method

Steps were:

- a. Collect and prepare input data
- b. Run simulation
- c. Compute means and standard deviations for variables of interest.

5. Results

The results of the baseline simulation consisted of a set of output statistics that could be used as a basis for future studies. In addition, they could be used as an indication of expected performance given the proposed (baseline) data upon which the simulation was based.

6. Evaluative Comments

- a. The data gathered are potentially useful to PMS 389.
- b. This study made a marginal contribution to overall model evaluation.
- c. Data preparation and model runs were performed more quickly and inexpensively than for previous applications.

VI. Intermediate Evaluation of SHIP II (See Ref. 8)

1. Background

The lack of adequate techniques for systematic model evaluation was recognized within NAVPERSRANDLAB

(See Introduction). The simulation research effort had progressed to the point where overall model evaluation was deemed necessary before substantial application could begin.

Criteria needed to be defined and propounded and a scheme for evaluation developed.

2. Objectives

The objectives of the SHIP II evaluation study were:

- a. To develop a methodology for model evaluation,
- b. To evaluate the effectiveness and utility of the SHIP II model.

3. Scope

The study was a general evaluation of SHIP II and included face validity evaluation and sensitivity analyses.

4. Method

a. General Approach

A generalized methodology for model evaluation was developed. The methodology was broad enough to cover other types of models as well as the SHIP II model. Then the methodology was followed to evaluate various technical characteristics of the SHIP II model. Model data for the evaluation were available from pilot runs and comparative analyses that had been performed.

b. Study Steps

- Develop evaluation methodology
- Collect and tabulate data - output data and data about the model
- Analyze SHIP II based on evaluative criteria and data.

Criteria included validity, reliability, sensitivity, practicality, relevance. (Ref. pp. E-3 through E-5 for Definitions or Ref. 6)

5. Results

- a. A comprehensive description of SHIP II was prepared.
- b. Results of applications of SHIP II were tabulated.
- c. An evaluation methodology was developed and reported.
- d. The methodology was applied to SHIP II, and the following aspects of the model were treated:

Validity

Reliability

Sensitivity

Practicality

Relevance

6. Evaluative Comments

- a. A number of methodological advances, including a single index of model value, were made.
- b. The model successfully met criteria for model goodness when certain of the independent variables were manipulated and when face validity was examined.
- c. The overall results demonstrated that further work with SHIP II could benefit Navy manpower research and planning.

VII. Two-factor Study (See Ref. 18)

1. Background

PMS 389 cooperated with NAVPERSRANDLAB in simulating DD-963 wartime operations. The data

from that set of runs was considered the "standard" DD-963 data set.

Previous applications of SHIP II had focused on the relationships between output (dependent) variables and single input (independent) variables. Yet one of the major reasons for using simulation modeling is to study the effects of interactions between independent variables, which are not easily represented analytically. This study was the first attempt to consider the effects of simultaneous variations of SHIP II independent variables.

2. Objective

The specific problem addressed in the study was to explore the relative effects of variations in manpower level and workload demand upon workload and task accomplishment.

3. Scope

The study was run on the ASW division of the DD-963 class ship. Data included:

- 20 men (this number was varied during the study)
- 17 watch stations
- 11 subsystems, including 100 equipments
- 113 PM tasks
- 11 Ship's work jobs (these jobs were varied during the study)
- 5 training exercises

4. Method

There were two independent variables. For each variable, five levels were selected, giving 25 combinations of values. For each of the 25 treatment conditions a simulation was run, using a combat scenario designed by PMS 389.

The results were graphed and interpreted, and were analyzed using a two way, fixed effects analysis of

variance model. Additionally, the relative proportion of the variance accounted for by each variable was calculated.

5. Results

The following were the 14 dependent variables of interest:

- mean watch hours
- percentage of standard Navy work week
- number of queues (maintenance manning)
- interrupts
- percentage of unavailability
- number of queues (equipment)
- PM delays
- PM jobs cancelled
- Ship's work hours left
- Ship's work interrupts
- Training exercises cancelled
- Training delays
- Training delay hours

The workload variation consisted of a systematic reduction in the amount of ship's work; the manning variation was a systematic reduction in the number of STG's. Table 1* summarizes the statistically significant results. Table 2* summarizes the implications of data for model validity.

* Reprinted from Special Research Report: A Two-Factor Study of Manpower Level and Work Demand, Schwartz and Harris, 1972.

TABLE 1

Summary of Variables with Significant
F Values ($F = 2.46$)

<u>Model Output Variable</u>	<u>Dependent Variable</u>	<u>F</u>	<u>Prop. of Variance</u>
<u>Personnel Record</u>			
Watch Hours	Number of STGs	303.34	0.91
SNWW Percent	Number of STGs	208.31	0.87
	Percent of Work- load	2.96	0.01
<u>Equipment Summary</u>			
Available Percent	Number of STGs	2.54	0.04
	Percent of Work- load	3.18	0.05
<u>Planned Maint. Summary</u>			
Delays	Number of STGs	220.64	0.89
Cancellations	Number of STGs	509.40	0.95
<u>FM-SA Summary</u>			
Hours Left	Number of STGs	64.01	0.47
	Percent of Work- load	31.32	0.21
	Interaction	4.33	0.09

TABLE 2

Summary of Implications of Data for Model Validity

<u>Dependent Variable</u>	<u>Independent Variable</u>	Results Tend to Support Model	Results Tend Not to Support Model	More Date Needed
<u>Personnel Summary</u>				
#1. Mean watch hours	Target group size Workload level	x x		
#2. Mean percent of SNWW	Target group size Workload level	x x		
<u>Maintenance Personnel Summary</u>				
#3. Mean number of queues	Target group size Workload level			x x
#4. Mean queue hours	Target group size Workload level			x x
#5. Mean number of interrupts	Target group size Workload level			x x
<u>Equipment Summary</u>				
#6. Mean available percent	Target group size Workload level		x x	
#7. Mean queues	Target group size Workload level	x	x	

<u>Dependent Variable</u>	<u>Independent Variable</u>	<u>Results Tend to Support Model</u>	<u>Results Tend Not to Support Model</u>	<u>More Data Needed</u>
<u>Planned Maintenance Summary</u>				
#8. Delays	Target group size	x		
	Workload level	x		
#9. Cancellations	Target group size	x		
	Workload level	x		
<u>FM-SA Summary</u>				
#10. Hours left	Target group size	x		
	Workload level	x		
#11. Interrupts	Target group size			x
	Workload level	x		
<u>Training Readiness Summary</u>				
#12. Cancellations	Target group size			x
	Workload level			x
#13. Delays	Target group size			x
	Workload level			x
#14. Delay hours	Target group size			x
	Workload level			x

In addition to examining the specific questions regarding the dependent variables, the study also addressed some general topics regarding experimental design and the application of the SHIP II model. The results of the F-tests indicated that the assumptions underlying the use of the analysis of variance (ANOVA) model may have been violated. If so, it seemed probable that the specific assumption in doubt was the linearity of the data, in which case a future study should investigate possible non-linear transformations of the data. This could be an important result in terms of long range plans for model applications.

6. Evaluative Comments

a. A new and useful adjunct to the SHIP II model was developed and is now available for future use with the model. It is a computer program called "Linkage" which selects appropriate variable classes and prints run values for them, disregarding non-relevant data. It outputs directly onto punched cards which are then used in various statistical analyses. Future SHIP II studies will be greatly expedited as a result, with a significant reduction in cost and time.

b. Many of the responses of dependent variables in this study demonstrated the model's construct validity (when workload requirement and manning levels were the independent variables).

c. The practical utility of the model for the solution of several classes of manpower problems was demonstrated.

d. There were minor flaws in model logic, which, on reexamination, had an adverse effect on equipment availability output measures. These will be corrected in the near future.

VIII. Reduced Manning Study (Ref. 32)

1. Background

The possibility of an all voluntary military force has caused manpower planners to consider the prospect of a significantly reduced manpower pool. NAVPERSRANDLAB is investigating proposed ways of meeting manning requirements with such a reduced personnel pool.

2. Objectives

a. To determine the effectiveness and efficiency of using SHIP II to investigate problems of reduced shipboard manning.

b. To develop and demonstrate a heuristic method of application.

c. To assess the suitability of a specific proposal - moving tasks ashore - to reduce shipboard manning requirements.

3. Scope

The study was general in nature; the objectives were not limited to a specific ship class or other data set. However, for time and convenience the data set was limited to a single division of men on the DD-963. It was assumed that study results would be generalizable to a total ship.

The data set encompasses the S division:

- 38 men in 5 ratings
- 27 watch stations
- 149 ship's work tasks
- 34 training exercises
- a one year scenario of wartime operations

4. Method

The general approach was a three-part iterative method.

a. A baseline run to establish statistics based on currently documented manning and tasks.

b. A reduced task run to establish statistics based on full manning with reduced task responsibilities.

c. A manning reduction based on the foregoing reduced task run, followed by a reduced manning run to verify the results. (If the reduction criteria were not satisfied, the manning reduction would be adjusted accordingly, and the reduced manning simulation would be re-run.)

5. Results

a. The baseline run produced a set of statistics against which the subsequent run results would be measured.

b. Of the 149 ship's work tasks, 64 tasks, totalling 316 manhours per week, were deleted on the assumption that they might be performed ashore. The simulation was run with full manning and reduced tasks.

c. On the basis of workload statistics generated in the reduced task run, and of remaining skill and supervisory requirements, 8 of the 38 men in the division were deleted. The tasks which had been assigned to those men and had not been eliminated were reassigned to other remaining men. The simulation was then run with the reduced manning to test the efficacy of the manning reduction.

The reduced manning set proved to meet the requirements set up for the demonstration. These success criteria were:

- all watch stations must be manned by division personnel,
- tasks could be performed by higher rated personnel than originally assigned, but not by lower rated men,

- average workload level at reduced manning-reduced tasks should approximate the level at full manning-full tasks.

The study showed that the SHIP II model was a good tool to use to investigate this type of problem. It demonstrated that the iterative method used was a sound approach to investigating the problem. Finally, it showed that moving ship's work tasks ashore might be an effective way to reduce shipboard manning requirements.

6. Evaluative Comments

This was the first attempt to apply the model heuristically as a planning tool. While no attempt to quantify the degree to which criteria of validity, etc., were met, it is felt the model is an excellent preliminary planning tool which aids in problem identification and generates data which form the basis for the creation of corrective methods.

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IV. DISCUSSION AND CONCLUSIONS

While the basic structure of the SHIP II simulation model, with its stochastic processes for determining equipment failure times and task completion times, and processes for establishing man-to-task assignments, is not difficult to understand, the number of manipulable and interactive variables make the model extremely complex. The task of comprehensive evaluation is equally complex.

If one considers the requirements necessary to evaluate response characteristics of a model with over 30 possible major* variables which can be used as independent variables and a like number of major dependent variables, one is faced with a huge cost and time problem. Only the most important variables of SHIP II can be considered in this evaluation study for obvious reasons. In general, it can be said that SHIP II meets the criteria for face validity, reliability, practicality, relevance and sensitivity for those combinations of variables thus far studied, minor flaws in data and logic notwithstanding.

The point has been made that for the ultimate test of validity there is no substitute for empirical validity studies. But considering the expense of such studies and considering the fact that revalidation might be required every time model logic is altered, it may not in fact be particularly cost effective to conduct such studies.

There are many untested features of SHIP II - the test and evaluation effort should, however, be guided by specific needs for applications on the part of potential research consumers.

Past applications of the SHIP II model have neglected exhaustive determinations of the statistical distribution characteristics of the model outputs. This could present a major problem where interpretation of results of studies is concerned. Most techniques applied to analysis of outputs have required assumption of normal or linear distributions. Whether these assumptions were true of the data generated by the model has not yet been determined.

* Major variables refers to a variable which can be considered a set of smaller components, e.g., workload, as a major variable, can be comprised of watch, PM, CM, etc. for each man, each division, etc.

For the studies thus far conducted, SHIP II has been shown to be useful in the following kinds of manpower problems:

- The study of effects* of reducing manpower, workload requirements or both simultaneously,
- The study of the effects of varying ships tempo of operations,
- The study of the effects of varying equipment reliability,
- The heuristic study of alternative ways of staffing and training selected ships functions,
- The study of the effects of altering skill levels of personnel,
- Detailed studies of workload balancing problems,
- All of the above for planned or actual, total or partial systems.

Currently the following deficiencies of SHIP II are recognized:

- No details of human performance are accounted for
- Deficiencies in program logic (which will be corrected) require that equipment availability statistics be manually adjusted prior to use in analysis of results of studies.
- The time and cost involved in data preparation are significant. This is true of most modeling efforts.

* Effects refer to effects on each model output statistic previously discussed.

- In-port conditions are not simulated.
- Persons intimately familiar with all aspects of the model must be connected with each application of SHIP II and associated programs. This is true of most complex models.
- The model in its current form can only be used on a CDC 3800 computer.

Application costs vary with the details of the study requirements and are primarily dictated by the input data collection and preprocessing effort, not computer time (approximately \$200 per hour and an average of \$2500 per detailed study). On the basis of past experience, approximately 3 man months are required to collect and preprocess a whole set of model input data for a study.

Output processing is accomplished by computer at minimal cost to the effort.

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